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(12) # EUROPEAN PATENT APPLICATION

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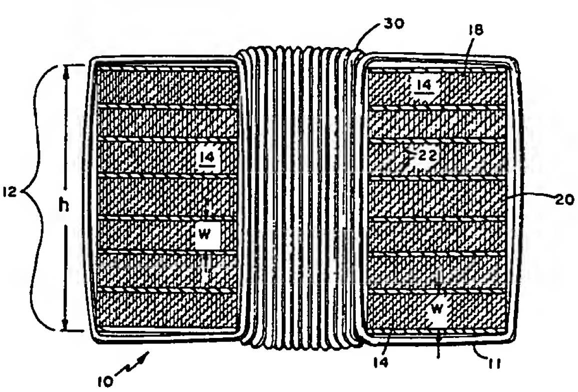
(54) **Core for electromagnetic induction device.**

(57) A magnetic core for an electromagnetic induction device has a plurality of magnetic core elements (14). Each of the core elements is formed by winding a plurality of layers of uninsulated strip (18) of magnetically permeable material. The core elements are juxtaposed together to form a core stack, the height of which is large relative to the strip width of each element. The core elements are electrically isolated from each other by insulating material (22) interposed between the elements at the region of juxtaposition.



EP 0 026 871 A1

DESCRIPTION

CORE FOR ELECTROMAGNETIC INDUCTION DEVICE

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to magnetic core structures for use in electrical induction apparatus such as transformers, motors, generators and the like.

Description of the Prior Art

Magnetic devices, such as transformers, motors, generators and the like oftentimes include wound core members composed of magnetically soft material. The material, in the form of continuous strip is typically wound on a suitable mandrel and annealed to relieve winding stresses. The mandrel is then removed from the core, which is cut and treated for receiving windings thereon.

One of the major problems with toroidal core members is the core loss produced by eddy currents present in and between wound layers of the strip. This loss, which varies as the square of strip width, is so large that it has previously been necessary to form the core from a number of laminated plates wound or stamped from the strip, individually coated with insulating material and wound or stacked one upon another on the flat side thereof. As a result, magnetic cores for electromagnetic induction devices have low operating efficiency and high construction and material costs.

SUMMARY OF THE INVENTION

Briefly stated the present invention provides

a magnetic core for an electromagnetic induction device that is economical to make and highly efficient in operation. The magnetic core comprises a plurality of magnetic core elements, each of which is formed by winding a plurality of layers of uninsulated strip of magnetically permeable material. The magnetic core elements are juxtaposed together to form a core stack, the height of which is large relative to the strip width of each element. The core elements are electrically isolated from each other by insulating material interposed between the elements at the region of juxtaposition.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood and further advantages will become apparent when reference is made to the following detailed description of the preferred embodiment of the invention and the accompanying drawings, in which:

Figure 1 is a perspective view of a transformer incorporating the composite core of this invention;

Figure 2 is a section taken through line 2-2 of Fig. 1; and

Figure 3 is an exploded perspective view illustrating the composite core construction of the transformer shown in Fig. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figures 1 and 2 of the drawings, there is shown generally at 10 an electromagnetic induction device having the magnetic core 12 of this invention. The magnetic core 12 comprises a plurality of magnetic core elements 14. Each of the core elements 14 is formed by winding a plurality of layers 16 of uninsulated strip 18 of magnetically permeable material. The elements 14 are juxtaposed together to form a core stack 20, the height, h, of which is large relative to the strip width, w, of each element. Core elements 14 are electrically isolated from each other by insulating material 22 interposed between the core elements 14 at

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the region of juxtaposition 24.

The strip 18 used to wind the magnetic core elements 14 is composed of magnetically soft material. Such material desirably has the following combination of properties: (a) low hysteresis loss; (b) low eddy current loss; (c) low coercive force; (d) high magnetic permeability; (e) high saturation value; and (f) minimum change in permeability with temperature. Conventionally employed magnetically soft material in strip form, such as high-purity iron, silicon steels, iron/nickel alloys, iron/cobalt alloys and the like, are all suitable for use in the practice of the present invention. Particularly suitable, however, is strip 18 of amorphous (glassy) magnetic alloys which have recently become available. Such alloys are at least about 50% amorphous, as determined by x-ray diffraction. Such alloys include those having the formula $M_{60-90}T_{0-15}X_{10-25}$, wherein M is at least one of the elements iron, cobalt and nickel, wherein T is at least one of the transition metal elements, and X is at least one of the metalloid elements of phosphorus, boron and carbon. Up to 80 percent of the carbon, phosphorus and/or boron in X may be replaced by aluminum, antimony, beryllium, germanium, indium, silicon and tin. Used as cores of magnetic devices, such amorphous metal alloys evidence generally superior properties as compared to the conventional polycrystalline metal alloys commonly utilized. Preferably, strips of such amorphous alloys are at least about 80% amorphous, more preferably yet, at least about 95% amorphous.

The amorphous magnetic alloys of which strip 18 is preferably composed are formed by cooling a melt at a rate of about 10^5 to 10^6°C/sec. A variety of well-known techniques are available for fabricating rapid-quenched continuous strip. When used in magnetic cores for electromagnetic induction devices, the strip 18 typically has the form of wire or ribbon. The strip 18 is conveniently prepared by casting molten material

directly onto a chill surface or into a quenching medium of some sort. Such processing techniques considerably reduce the cost of fabrication, since no intermediate wire-drawing or ribbon-forming procedures are required.

The amorphus metal alloys of which strip 18 is preferably composed evidence high tensile strength, typically about 200,000 to 600,000 psi (1.38-4.14 x 10^6 kPa), depending on the particular composition. This is to be compared with polycrystalline alloys, which are used in the annealed condition and which usually range from about 40,000 to 80,000 psi (2.76-5.52 x 10^6 kPa). A high tensile strength is an important consideration in applications where high centrifugal forces are present, such as experienced by cores in motors and generators, since higher strength alloys allow higher rotational speeds.

In addition, the amorphous metal alloys used to form strip 18 evidence a high electrical resistivity, ranging from about 160 to 180 microhm-cm at 25°C, depending on the particular composition. Typical prior art materials have resistivities of about 45 to 160 microhm-cm. The high resistivity possessed by the amorphous metal alloys defined above is useful in AC applications for minimizing eddy current losses, which, in turn, are a factor in reducing core loss.

A further advantage of using amorphous metal alloys to form strip 18 is that lower coercive forces are obtained than with prior art compositions of substantially the same metallic content, thereby permitting more iron, which is relatively inexpensive, to be utilized in the strip 18, as compared with a greater proportion of nickel, which is more expensive.

Referring to Figs. 2 and 3 of the drawings, each of the magnetic core elements 14 is formed by winding successive turns of strip 18 on a mandrel (not shown). During winding of successive turns, strip 18 is kept under tension to effect tight formation of the core element 14. The number of turns required for a given

core element 14 can range from a few turns to several thousand turns, depending upon the power capacity of the electromagnetic device desired. When the required number of turns are wound for a given core element 14, the strip 18 is cut across the width, w, thereof, the outer turn being held in wound relation to the preceding turn. Typically, the cut end of the last turn of strip 18 is spot welded, clamped or otherwise secured to the wound core element 14.

When sufficient turns have been wound to form a given magnetic core element 14 as above described, the mandrel is removed therefrom to produce the core element 14 shown in Fig. 3. The core element 14 has a width defined by the width of strip 18 and a build defined by the number of turns of strip 18 times the strip thickness, t. Amorphous metal strip is relatively thin as compared to rolled crystalline strip. Moreover, the composite core construction of magnetic core 12 eliminates the necessity for individually coating each wound layer of strip 18 used to form core element 14. As a result, the core element 14 can be wound into a smaller, lighter element at lower construction, processing and material costs than magnetic cores having an insulated interlaminar construction. Generally, the width of strip 18 ranges from about .25 to 2.5 centimeters and the thickness of strip 18 ranges from about 1 to 2 mils. The build of each core element 14 can range from as low as 4 mils to as great as 25 centimeters or more depending upon the power requirements of the electromagnetic device.

Magnetic core 12 is assembled by sandwiching a layer of insulating material 22 between plural core elements 14. The core elements 14 may be bonded together by the insulating material 22. Alternatively, core elements 14 and insulation layers 22 can be placed successively on a spool composed of thermoplastic or thermosetting material. The number of core elements 14 used to construct magnetic core 12, as well as the

dimensions of the core elements 14 and overall height, h, of the magnetic core 12 will vary depending on the power capacity and operating frequency of the electromagnetic device. For electromagnetic devices having an operating frequency of 60 Hz and a power capacity ranging from 100 to 20,000 watts, the maximum acceptable strip width is about 1 inch (2.54 cm) the number of core elements 14 used to construct magnetic core 12 is about 3 to 10, the height, h, of magnetic core 12 is about 2 to 10 inches (5.08-25.4 cm) the inside diameter of each core element 14 is about 1 to 6 inches (2.54-1.52 cm) and the outside diameter of each core element 14 is about 2 to 20 inches (5.08-50.8 cm). For electromagnetic devices having an operating frequency of about 10 KHz and a power capacity ranging from 100 to 20,000 watts, the maximum acceptable strip width is about 1/4 inch (6.3×10^{-1} cm), the number of core elements 14 used to construct magnetic core 12 is about 3 to 10, the height, h, of magnetic core 12 is about 2 to 10 inches (5.08-25.4 cm), the inside diameter of each core element 14 is about 1 to 3 inches (2.54-7.62 cm) and the outside diameter of each core element 14 is about 2 to 10 inches (5.08-25.4 cm).

The insulating layers 22 disposed between core elements 14 can be composed of any suitable insulating material such as thermosetting or thermoplastic material, glass cloth, fiberglass, polycarbonates, mica, CAPSTAN, LEXAN, fish paper and the like, having the required flexibility, dielectric strength, toughness and stability at the design operating temperature of the magnetic core 12, normally in the vicinity of 130°C. As shown in Fig. 3, insulating layers 22 are in the form of a flexible film having a thickness of about 1/2 mil and inside and outside diameters substantially equivalent to those of core elements 14. Electrical isolation of core elements 14 can alternatively be accomplished by disposing insulating material over part of the build portions between adjoining core elements 14. Thus, the insulating

layer 22 disposed between adjoining core elements 14 can have the form of a spider or other suitable configuration adapted to physically separate and electrically isolate the adjacent core elements 14. In such a case, electrical isolation of core elements 14 is effected by an insulating layer 22 comprised in part of air. Still further, the insulating layer 22 can be painted, sprayed or otherwise applied to one or both of the adjoining surfaces of core elements 14.

Construction of a transformer 11 incorporating magnetic core 12 can be readily effected by toroidal winding of primary and secondary turns 30, 32 of copper or aluminum wire or ribbon about the magnetic core 12, or by hand threading the copper or aluminum wire turns about the magnetic core 12 in a conventional manner. The elimination of interlaminar insulation afforded by the sectionalized construction of magnetic core 12 substantially reduces the length of the copper turn required, and decreases the copper loss of the electromagnetic device 10.

The reduction in core loss resulting from the composite core construction of magnetic core 12 has been demonstrated by a 15 KVA transformer wound with seven core elements 14 of 1 inch (2.54 cm) wide uncoated strip 18.

If the transformer core had been wound with uncoated strip 18 in the form of wide ribbon in a single section, a current, I, would have flowed between the ribbon layers. This current would be $\frac{E}{R}$ where E is the voltage induced in the magnetic core and R the effective interlayer resistance. As per Faraday's Law of Induction, E is proportional to the frequency, the flux density and the core area. R, the effective interlayer resistance, is proportional to the interlayer resistivity and inversely proportional to the area of contact between the layers. The interlayer core loss would then be: $P = I^2R = \frac{E^2}{R}$

If, on the other hand, the magnetic core 12 is sectioned

into "n" number of core elements 14 insulated from each other, in accordance with the invention, there will now be a current i flowing in each core element 14 due to an induced voltage e and an interlayer resistance r. Since the core area of the core element 14 is now n times smaller, the induced voltage e is:

$$e = \frac{E}{n} \qquad (1)$$

The contact area determining the interlayer resistance is now n times smaller, therefore the effective interlayer resistance of each element is:

$$r = nR \qquad (2)$$

The interlayer core loss, p, of each element will be:

$$p = i^2 r = \frac{e2}{r}$$

Substituting for e and i from equations 1 and 2:

$$p = \frac{E^2}{R\ n3}$$

Since the core is composed of n sections, the total interlayer core loss, P, will be:

$$P = np = \frac{E^2}{R\ n2}$$

Or, in other words, n2 times less than when the core is wound as a single element. In the 15 KVA transformer consisting of seven elements, the interlayer core loss is 49 times lower than it would be if it had been wound as a single section with 7 inch (17.78 cm) wide uncoated strip.

Having thus described the invention in rather full detail it will be understood that these details need not be strictly adhered to but that various changes and modifications may suggest themselves to one skilled in the art, all falling within the scope of the invention as defined by the subjoined claims.

What is claimed is:

1. A magnetic core for an electromagnetic induction device, comprising:

a. a plurality of magnetic core elements, each of said core elements being formed by winding a plurality of layers of uninsulated strip of magnetically permeable material;

b. said magnetic core elements being juxtaposed together to form a core stack, the height of which is large relative to the strip width of each element; and

c. said magnetic core elements being electrically isolated from each other by insulating material interposed between the elements at the region of juxtaposition.

2. A magnetic core as recited in claim 1, wherein said strip is composed of a metal alloy that is at least 50 percent amorphous and has a composition defined by the formula $M_{60-90}\ T_{0-15}\ X_{10-25}$ wherein M is at least one of the elements iron, cobalt and nickel, T is at least one of the transition metal elements and X is at least one of the metalloid elements phosphorus, boron and carbon.

3. A magnetic core as recited in claim 2, wherein up to 80 percent of component X is replaced by at least one of aluminum, antimony, beryllium, germanium, indium, silicon and tin.

4. A magnetic core as recited in claim 2, wherein said strip is at least about 80 percent amorphous.

5. A magnetic core as recited in claim 2, wherein said strip is at least about 95 percent amorphous.

6. A magnetic core as recited in claim 1, wherein said core stack has a height ranging from about 2 to 10 inches (5.08-25.4 cm) and said strip width ranges from about .25 to 2.5 centimeters.

7. A magnetic core as recited in claim 1,

wherein said plurality of core elements ranges from 2 to 10.

8. A magnetic core as recited in claim 1, wherein each of said core elements has a build ranging from about 4 mils to 25 centimeters.

9. An electromagnetic device having a primary, a secondary and a magnetic core, said magnetic core comprising:

a. a plurality of magnetic core elements, each of said core elements being formed by winding a plurality of layers of uninsulated strip of magnetically permeable material;

b. said magnetic core elements being juxtaposed together to form a core stack, the height of which is large relative to the strip width of each element; and

c. said magnetic core elements being electrically isolated from each other by insulating material interposed between the elements at the region of juxtaposition.

10. An electromagnetic device as recited in claim 9, wherein said device is a transformer.

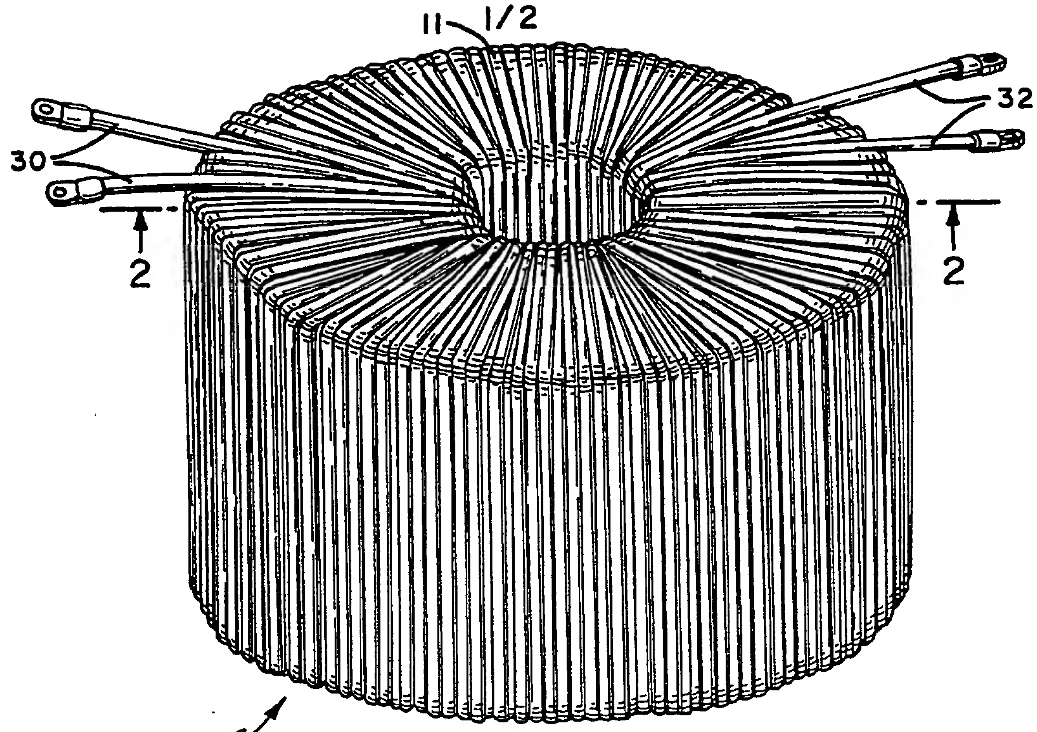


FIG. 1

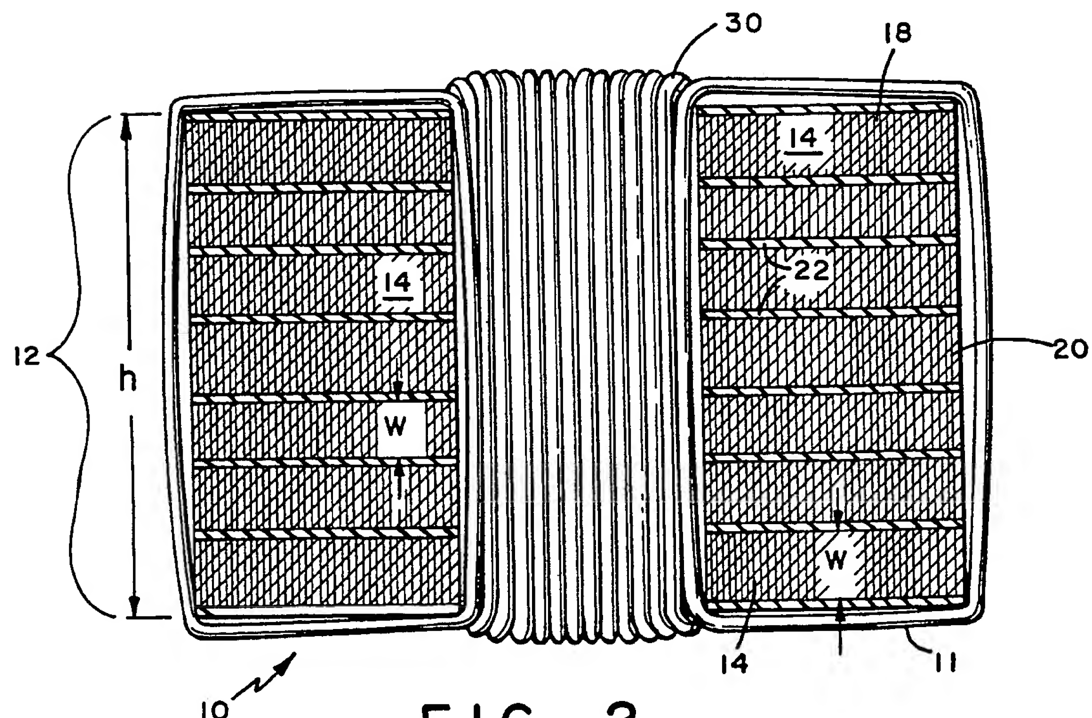
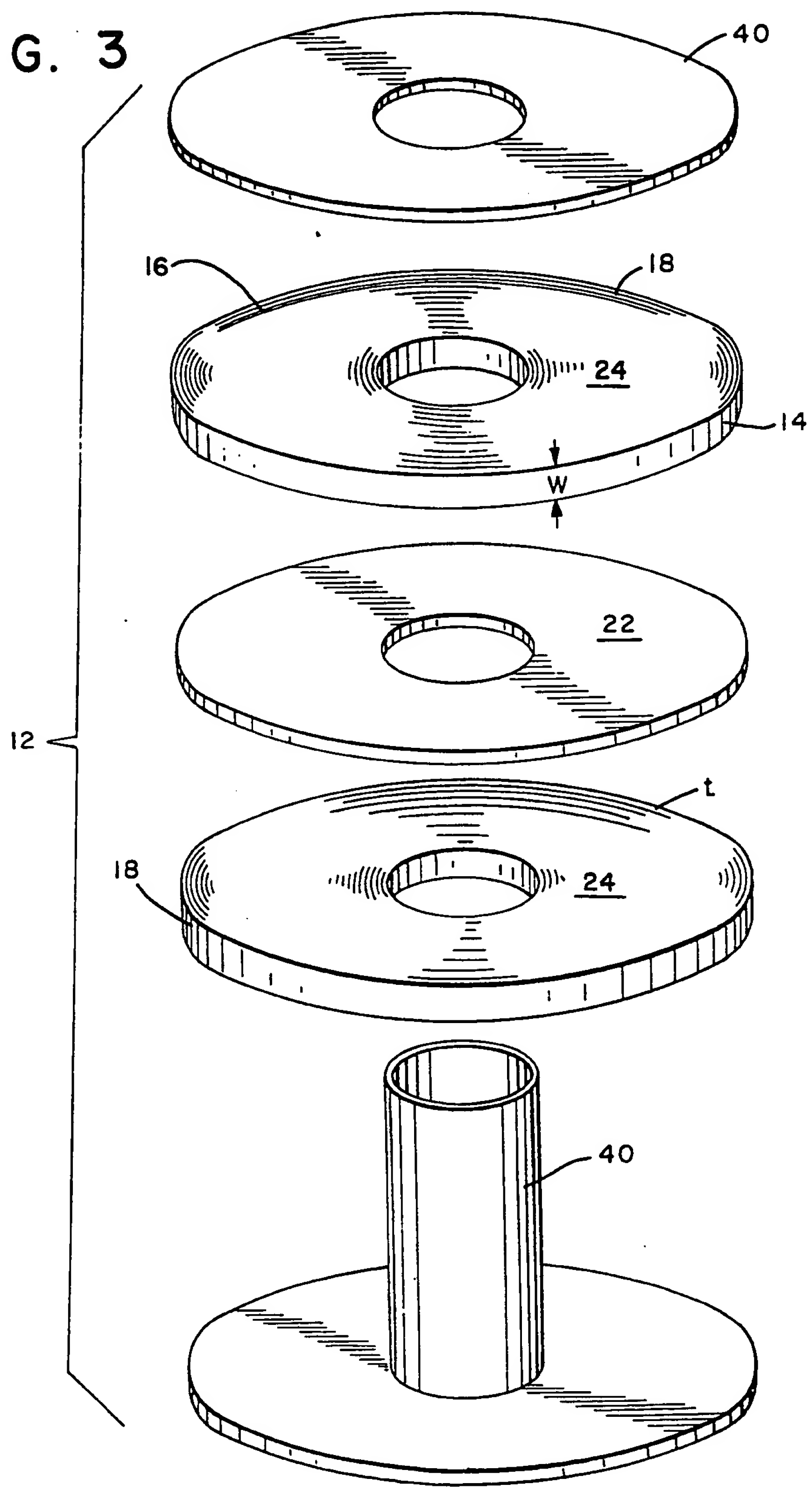


FIG. 2

FIG. 3



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EUROPEAN SEARCH REPORT

Application number
EP 80 10 5694

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
	GB - A - 1 453 154 (ELPHIAC) * Page 1, lines 56-88 * --	1
	US - A - 2 909 742 (GENERAL ELECTRIC) * Column 1, lines 15-16 * --	1,9,10
	US - A - 4 056 411 (HO SOU CHEN) * Column 2, lines 12-40; column 3, lines 44-50 * --	2,3
A	DE - C - 937 185 (SIEMENS)	
A	GB - A - 1 525 959 (HO-SOU CHEN)	
A	US.- A - 3 838 365 (ALLIED CHEMICAL CORP.)	
A	US - A - 4 038 073 (ALLIED CHEMICAL CORP.)	
A	US - A - 4 116 728 (GENERAL ELECTRIC) ----	

CLASSIFICATION OF THE APPLICATION (Int. Cl.³)

H 01 F 27/24
1/16

TECHNICAL FIELDS SEARCHED (Int. Cl.³)

H 01 F 27/24
3/04
31/00
1/14
1/16

CATEGORY OF CITED DOCUMENTS

X: particularly relevant
A: technological background
O: non-written disclosure
P: intermediate document
T: theory or principle underlying the invention
E: conflicting application
D: document cited in the application
L: citation for other reasons

&: member of the same patent family, corresponding document

X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	17-12-1980	VANHULLE

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